Title
Organic Contaminants in San Diego Bay: Assessment of Storm Water

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“Organic Contaminants in San Diego Bay: Assessment of Storm Water”

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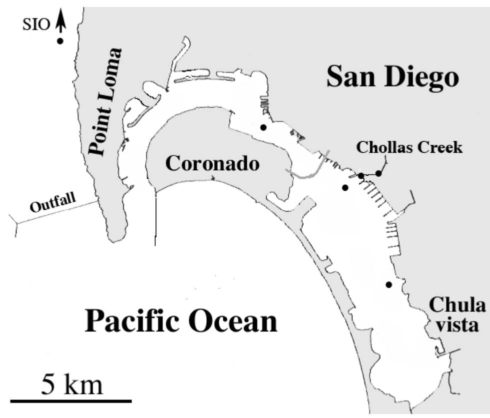
I assessed whether storm water is a source of organics that could impact fauna living in San Diego Bay. I examined the legal framework, scientific aspects, economics, and psychology of this issue. The science experiment consisted of using brittlestars in a laboratory experiment in order to assess organic contaminant toxicity. Today, storm water flows into our waters without any sort of treatment (Environmental Protection Agency – www.EPA.gov accessed 2007). Laws and regulations are strong forces in environmental improvements (Oskamp, 2006). San Diego's programs in place are ineffective and San Diego Bay's marine and aquatic ecosystems are the second most impaired in the state (EPA, 2007). What have state and local governments done to enforce storm water requirements in San Diego? What works and doesn't work and could be done differently? If the United States considered environmental protection a human right, would we be dealing with the uncertainties of the language and the discrepancies in the National Pollution Discharge Elimination System (NPDES) and storm water programs? Is the Environmental Protection Agency (EPA) enforcing goals and regulations that are too ambitious? How can the EPA create and implement an effective water pollution education strategy? Would valuing clean water help society and decision makers resolve some storm water issues?

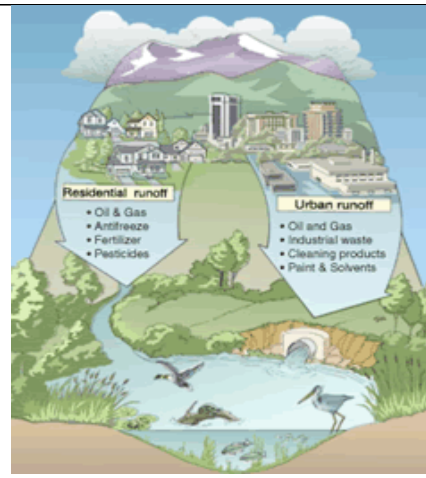
San Diego bay is heavily used for commercial, industrial, military, and recreational activities. In 1996, the National Oceanic and Atmospheric Administration labeled San Diego bay as the second most toxic bay in all of the United States. San Diego bay is also listed on the Clean Water Act (CWA) Section 303(d) list for impaired benthic communities and toxic sediment containing high levels of contaminants, among which mainly metals, but also organics. This list places contaminated areas of concern on a priority toxic cleanup list. San Diego bay has been extensively studied for its heavy metal pollution; in contrast, little information is available on organic contamination in the bay. Storm water pollutants are the nation's biggest contributors to water pollution, which is impairing general coastal ecosystem health and biodiversity. San Diego bay receives urban runoff, which is known to be a possible non-point source for organic contaminants.

Figure 1. Map of Area of San Diego with Chollas Creek, identified as one of the main non-point source pollution for San Diego Bay.



Storm water is defined as the precipitation and water flow travel through urban development down its path to a river, or wetland, or bay, or ultimately our ocean. Precipitation may flow over the soil surface or commonly cement in urban areas, or beneath the surface. About half is transpired by plants or evaporates. The other half of the subsurface water exits through the surface within a few minutes to a few months and joins the runoff. There are two kinds of storm water, residential, which consists of pollutants from cars and gardens, and urban runoff which contains everything from industrial wastes to paint products. This means some of the contaminants are heavy metals, toxic chemicals, nutrients, pesticides, and petroleum byproducts to name a few (Lewis, 2001).

Figure 2. Schematic diagram representing storm water process (courtesy of urbandale.org.)



The watershed mainly consists of, -in descending order of area usage-, residential, parks, commercial and industrial areas. The Navy and NASSCO, (National Steel and Shipbuilding Company, a major ship construction yard), directly runoff into the Bay. When it rains, the water runs through the developed areas, down the streets and into the creeks: Chollas, Switzer, and Paleta which drain into SD Bay (Schiff, 2003, www.sandag.cog.ca.us accessed 2007, www.sccwrp.org accessed 2007).

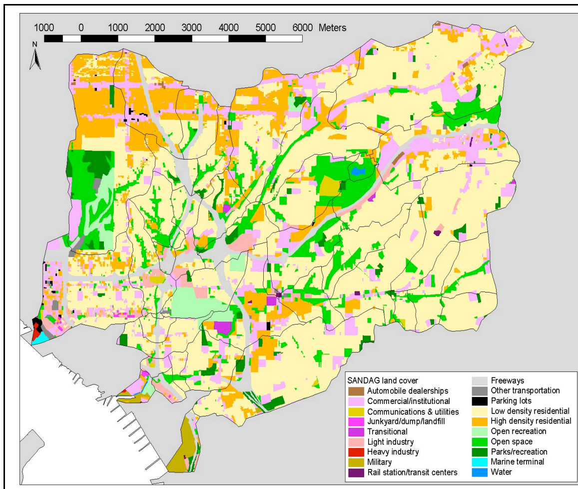


Figure 3. SANDAG map of land uses of Pueblo watershed.

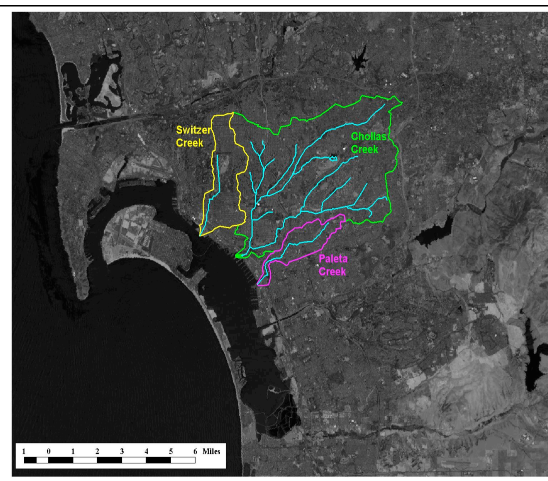


Figure 4. Arial m nap of Pueblo watershed. (courtesy of SCCRWP.)

I will concentrate on pollutants from oil and gas byproducts: Polycyclic Aromatic Hydrocarbons. PAHs are one of the most prevalent organic pollutants in our waters and not very much is known about how they affect marine life and their fate in the ocean. The most common are the 5 and 6 ringed which have low solubility's in water and therefore are usually found in soil and sediment or particles suspended in water and air. PAHs are a problem because some are known human carcinogens and they have the potential to become more abundant. I picked the most appropriate PAH mixture available by incorporating all 3 types of PAHs, the most common PAHs in the world, and ones found in diesel and tar which are likely to be dispersing via storm water (Luch, 2005, Fetzer, 2000).

There is a lack of studies that speculate the chemical interaction and cycle of organics in seawater, sediment, and in benthic organisms.

Law and Policy

Why is storm water the leading cause of water pollution nationally?

There are many issues involved with implementing the Clean Water Act (CWA). Currently, most municipal separate storm water sewer systems do not go to a sanitary sewer system therefore, the water is released into the receiving waters untreated. Every state and major watershed in the United States is impaired by ineffective regulation of NPS runoff. San Diego's programs in place are ineffective and San Diego Bay's marine and aquatic ecosystems are the second most impaired in the state (EPA, 2007).

What have state and local governments done to enforce storm water requirements in San Diego?

In the last few years, significant regulatory action has occurred in this area, especially in California (Minan 2003, 2005).

What works and what doesn't work?

The CWA calls for storm water programs but uses undefined language that causes uncertainty in the implementing process causing legal disagreement and regulatory uncertainty.

Laws and regulations are strong forces in environmental improvements (Oskamp, 2006). The Clean Water Act (CWA) is based on the Commerce Clause "To regulate Commerce with foreign Nations, and among the several States, and with the Indian Tribes." Because commerce is also done through navigable waters, these waters shall also be regulated. The CWA says "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The CWA was written to protect our aquatic resources. The CWA gives Congress the authority to regulate pollution in United States waters by controlling discharge of pollutants at the source (Minan, 2003).

The CWA has two regulatory approaches. One approach is to control discharge of pollutants by using effluent limits. Effluent limits are set in uniform, technology - based terms. This means dischargers can pollute into waters but are regulated by the effluent limits in their permit. The second approach is regulating dischargers based on their impact to receiving water quality. Impact on water quality is the amount of pollution allowed determined by the use and pollution capacity of the water body (Minan, 2003).

The CWA also has two phases: multiple categories and menus of best management practices. Multiple categories of regulated parties allow permittees to be treated on an individual basis. Best management practices are designed to fit any type of land use that pollutes storm water. (Wagner, 2006)

The CWA contains a number of different programs: the National Pollution Discharge Elimination System (NPDES) program, the Pretreatment program, the Non Point Source (NPS) program, the Dredge and Fill program, and the Oil Spill program. The NPDES is a point source program which contains the storm water system program. I will concentrate on the storm water system because storm water is the leading cause of pollution in our waters (Minan, 2003).

The CWA was originally designed to address point sources (or pollution coming out of a factory into a river), not non-point sources, (or storm water). In 1987 the CWA was amended and the municipal storm water program, called the Municipal Separate Storm Sewer Systems (MS4) program, was added to section 402(p) of the CWA saying that the MS4 system should be treated as a point source and from then on was apart of the industrial NPDES point source program. MS4 was added to NPDES because MS4 discharges into navigable waters. Section 402(p) says the MS4 program shall contain requirements to prohibit non-storm water discharge into the MS4 system and controls to reduce the amount of pollutants coming out of the MS4 system to the maximum extent possible (MEP). It also says the MS4 system shall comply with any appropriate Administrator or State provisions. The requirements for MS4 are such that permits may be issued on a system – wide basis which means co-permittees may share a single permit which makes the monitoring, analysis, development and implementation easier.

Currently, the MS4 does not go to the sanitary sewer system and discharges into the receiving waters untreated (Minan 2003, 2005).

Section 303 of the Clean Water Act established the water quality standards (WQS) and the Total Maximum Daily Load (TMDL) programs. TMDLs are the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. Some of San Diego's organic pollutant TMDLs have not yet been decided because of lack of study in this particular field and hopefully this project will help with the decision making process (www.epa.gov accessed 2007).

The Environmental Protection Agency (EPA) is responsible for issuing pollution permits to dischargers unless the EPA delegates the responsibility to a State program that proves equal to the federal program. In California, the nine Regional Water Quality Control Boards (RWQCB) gained responsibility for issuing and reviewing regional permits during the 1990's and became a leader in changing the status quo. Then in 1998 California's RWQCB's added the Storm Water Enforcement Act to the Water Code. This meant California was going beyond the Federal CWA requirements. The San Diego MS4 permit is at the head of California's regulatory effort. 1)Adding the Storm Water Enforcement Act to the Water Code, 2) the fit between MEP and the language "such other provisions" in the section 402(p) and 3) high economic and environmental stakes are some of the reasons of the storm water political controversy (Minan, 2003).

As soon as the MS4 program was added to the NPDES program in 1987, there has been controversy about the applications of the CWA. Administrative decisions were resolved by the State Water Resources Control Board, but there were petitions challenging storm water permits, legal disputes elevated all the way to the Supreme Court. A lawsuit by the

Building Industry Association challenged San Diego MS4 permit. First of all, it is difficult to use a point source program as a model for a non point source program that has many unique characteristics. The MS4 is not subject to the same types of requirements as more traditional point sources. MS4 permits differ from NPDES permits by their technology – based treatment standards and effluent limits. This is because of the variability of flow, pollutant type, and concentration of storm water discharge. Weather and urbanization affect the volume and velocity of storm water. This discrepancy of the MS4 system and traditional systems under the NPDES program fueled disagreement (Minan, 2003).

Secondly, disagreement and regulatory uncertainty came about with the fit between MEP and the language "such other provisions" in the section 402(p). Sometimes the states were more stringent than the MEP that the federal law was imposing. Some states, like California, were using a Water Quality Standard in storm water permitting with added requirements to the EPA's regulation, (the MEP). The EPA and authorized states can prohibit MS4s that violate the WQS. MEP was not defined and WQS was not mentioned in the CWA. The CWA only called for a practicable standard. The EPA decided MEP was undefined in order to create regulatory flexibility to fit the specific needs of the source of discharge. Regulators and environmentalists are concerned with whether WQS or MEP should be the permit limit. Therefore, the uncertainty of MEP and the language in section 402(p) brings about controversy (Minan 2003, 2005).

Thirdly, there is controversy because the economic and environmental stakes are high. Urbanization and thus development increases impervious surfaces meaning there is less soil to absorb precipitation and reduce pollutant loads, making the waters not suitable for swimming or living near. The building industry is a stakeholder because construction activities are regulated under the industrial storm water permit requirements and most completed development projects discharge into the MS4 system. For most local governments the cost of compliance must be balanced against the demand for public services. Building industries want to make sure the standards are not set too high because they don't want to be subject to high fines for noncompliance. On the other hand many environmental agencies are fighting for provisions that will be sufficient in protecting our aquatic and marine resources (Minan 2003, 2005).

On January 24, 2007 I attended the San Diego Regional Water Quality Control Board (SDRWQCB) Meeting concerning San Diego's municipal storm water permitting. Things began to get heated when the topic of waste discharge requirements was debated. Parties were yelling and fighting for the sake of their businesses. The SDRWQCB is in general agreement with the State RWQCB's order prohibiting sanitary sewer overflows that will supersede the region's current regulations. This means the regulations in San Diego will be stricter and affect the sewage collection agencies. A stricter regulation also means better water quality for the beaches and wetlands downstream.

The SDRWQCB asked the State for clarification to the first proposed change in the permit including language on implementing the change. The Board disagreed with the second change by saying the permit should not delete the "into and" language, meaning the SDRWQCB thinks pollutants should be allowed to be treated and then discharged into the storm drains.

The last disagreement is that the SDRWQB believes the retail gasoline outlets should be included under the Standard Urban Storm Water Mitigation Plan requirements. In other words the permit should address the gasoline pollutants and their impact on receiving waters.

This meeting was extremely emotional yet efficient at covering its goals to discuss the new sanitary sewer overflow regulations and how they will be implemented with permits. Now, we just have to wait and see how effective the enforcement of the new sanitary sewer overflow regulations turn out to be (SDRWQCB meeting January 24, 2007).

If the United States considered environmental protection a human right, would we be dealing with the uncertainties of the language and the discrepancies in the NPDES and storm water programs?

The government fails to address the scientific and technological limitations when designing environmental standards and regulations. Therefore, is the EPA enforcing goals and regulations that are too ambitious? Certain conditions need to be taken into account when implementing and evaluating an effective education strategy. The EPA has created an extensive information and education profile on its website as a strategy to help implement the storm water programs more effectively. Knowledge is a strong predictor of behavior but with the addition of motivators and normative beliefs, together would these conditions make the EPAs education strategy more effective?

There are a number of solutions to the United States problems with storm water policy writing, implementation, and enforcement. While cases in the United States are arguing about how the degradation of nature will affect our economy, India and Brazil recognize environmental quality as a right to life. (Fernandes) One solution to current law and policy is making environmental protection a human right in the United States. If environmental protection was considered a human right, we wouldn't be spending time arguing over what is a substantial economic concern. There are many situations dealing with water pollution in the United States that reveal how citizens' human rights were infringed upon because of the lack of legal regulation of environmental protection. In California for example, Ventura County's 1959 meltdown is causing over 800 cancers in a 60 square mile radius in Ventura County because the toxic wastes from 1959 are found in these people's drinking water today (Ventura Star October 6, 2006). Brazil and India are good examples for the United States to learn how important environmental health is for human health which is important to the quality of life. Considering all these cancers in the Ventura example, environmental protection should be considered a human right in the United States.

A technical solution is to combine sanitary and storm sewers or to simply treat storm water but, this solution is considered not economically or technologically feasible at this point in time (Minan, 2003). Wagner believes these technological and scientific information limitations need to be taken into account before designing the regulations. There have been similar failures in other environmental regulatory programs. The programs do not take into account scientific and technical information limitations. This hinders the ways of regulating pollution or the manufacturing of toxic products because we can't create regulations and expect science and technology to provide a means to achieve certain goals. We need to know what science and technology offer when designing these regulations. Since the storm water programs do not take information limitations into account the public and permittees have run into this problem after the law was implemented. There is the argument that this need for better technology creates a market incentive for technology innovations. But, the problem of not having affordable and good technology when the standards are set will reduced the storm water program and EPA's effectiveness because either the EPA has trouble enforcing the standards or local and state governments are not happy about EPA's more stringent requirements. Ultimately, the storm water program would be more effective if the requirements were enforceable by taking into account technological and scientific information limitations while designing the regulations (Wagner, 2006). Farber argues that insufficient compliance and/or enforcement is the underlying problem for any kind of governance and/or environmental law. No matter how great an environmental law, if the enforcement or compliance isn't there, the law is powerless (Farber, 1999).

Creating new policy also raises the issue of monetary support. Can we afford a new water treatment system? "What is needed is funding to support progressive change, which of course involves political (legislative) balancing of priorities." (John Minan, interview April 10, 2007.) Making TMDLs can be political and have to do with the people in office. Society is also involved in the decision making process; solutions begin at the personal level. What does society care about? Society does not value clean water. (Donna Frye, interview April 10, 2007.)

Economics

Anywhere from policy, to resources management, to development, quantifying the ecosystem services to make these services comparable with economic services, and manufactured capital is pertinent in decision making. Non point source pollution cannot be easily quantified nor the value of marine biodiversity.

Valuing ecosystems is important in decision making concerning ecosystem services. Costanza, 1997 wrote an article, *The Value of the World's Ecosystem Services and Natural Capital*, to accelerate a movement towards valuing ecosystem services. Daily, a biologist, originally talks about her views on valuing environmental resources. Many economists including Tomam criticized the technical aspects of Costanza's article. There are good examples of current markets or ideas of valuing a part of an ecosystem and incorporating its value into the market. Despite some technical economic flaws, Costanza's argument of valuing ecosystem services is imperative for conservation measures.

Costanza says that ecosystem services are not given enough significance in policy decisions in his paper. This statement is important because human welfare depends on these ecosystem services. Costanza actually puts the value of about 33 trillion dollars a year on the world's total ecosystem services value which is worth much more than the 18 trillion dollars per year for the GNP of the world. 33 trillion dollars is an underestimate because it does not include all types of ecosystems and the value of the ecosystems would increase the more we understand them. Also, if the value of ecosystem services were paid for the GNP would be much greater. Since ecosystem services are not included in the market they are not represented correctly in decision making. It appears that the benefits of constructing a project outweighs its costs when the fact of the matter is the actual costs and benefits of the ecosystem services that are being compared to the project are not all accounted for. Costanza goal was to also invigorate and accelerate more research and debate on valuing ecosystems. Knowing more about the ecosystem will make the values become more precise and therefore change the decisions that are being made about important ecosystems. I believe the evolution of valuing sustainable energy around the globe is a solution countries are investing in.

Psychology

In dealing with the problems of the storm water program implementation, the EPA has set up an extensive information and education strategy on its website. The EPA also added implementing detail to the 402(p). There are pages of information to download off the EPA website regarding all the provisions in the CWA and MS4 program. This information is so long it can't be downloaded on some home computers. Education resources for the public and for teachers are also located on the website in great length. (EPA) Knowledge is a strong predictor of behavior. With the addition of motivators and normative beliefs, together these conditions make the EPAs education strategy more effective.

The education resources for teachers are a good way of effectively changing behaviors. It is easier to change behaviors of children because they have less bad habits to unlearn. Children also have a longer period of impact on the environment. Children may also promote good environmental behaviors on parents and others (Dwyer, 1980).

In the 1970s some researchers saw the value of applying behavior analyses to larger groups and to problems related to environmentally related behaviors. Research interest declined in the 1980's due to lack of support and the difficulty working with public policy, large systems, and cultural practices. There was also a lack of framework for coordinated research. Geller proposed a framework that consisted of communication/ education strategies, activators, and consequences. Dwyer believes the framework also needs to take into account active participation, a program that promotes social support, response information, and rewards and penalties (Dwyer, 1980).

The procedural knowledge is presented on the website targeting an individual's situational predictors by informing people where, when, and how to decrease storm water pollutants. Decreasing pollutant discharge from non-point sources are done with behaviors for example, construction projects using best management practices, or the public conserving landscape irrigation, or proper disposal of car oil. According to Wesley Schultz, a psychology researcher, knowledge is a strong and consistent predictor of recycling behavior, which can be associated with other environmentally related activities. Education strategies that present information in order to gain or change knowledge may be inexpensive but can only be effective with small and short term behavior changes (Schultz, 2006).

Along with knowledge, Schultz also believes action and interest in community activities reinforces the knowledge. Action, for example, is when a person practices proper disposal of car oil, he or she learns more about the behavior. Interest in community activities causes an individual to learn more about the storm water provisions in order to participate in community storm water programs (Schultz, 2006). In the year 2000 the Beaches Environmental Assessment and Coastal Health Act was established and gives grants to help increase water monitoring efforts. These organizations make up San Diego's citizen water quality monitoring consortium: Coastkeeper, Surfrider, San Diego Stream Team, City of San Diego Stormwater Pollution Prevention Program (Think Blue), County of San Diego Department of Parks and Recreation, San Diego County Water Authority, San Diego Futures Foundation, San Diego Regional Water Quality Control Board, San Diego State University, Sister Schools of San Diego, and Southwestern College. (http://www.sdcwmc.org)

In order for the EPA to design an effective education and information strategy to implement the CWA, the EPA must consider conditions under which an information and education strategy would effectively change behavior. Schultz believes impact knowledge, or an individual's beliefs about the consequences of recycling, needs to be accounted for when designing an effective education strategy. This has to do with knowing that storm water is the leading cause of water pollution nationally and decreasing pollutant discharge directly decreases the national storm water pollution problem. Oskamp reinforces this by stating that factual data promotes good public policies. Impact knowledge is important in the value-belief-norm theory where all three together can effectively change behavior. Even though lack of knowledge is a barrier to behavior, knowledge does not provide a motive for behavior (Oskamp and Schultz, 2006).

In order for information and education to sufficiently change people's behaviors, a normative education program must be considered as a motivator. Normative knowledge is the beliefs of the behaviors of others. Normative beliefs are the perceptions of social pressure to do the environmentally related activities. There are two types of social norms: descriptive and injunctive. Descriptive social norms are beliefs about what others are doing and injunctive social norms are beliefs about what others think should be done. There are also personal or social norms. Personal norms are feelings of obligation and social norms are the appropriateness of behaviors. According to Oskamp and Schultz, studies have shown a strong positive relationship between normative beliefs and behavior which in turn can be related to other environmentally related activities. After engaging in a behavior people tend to think it is more common than it really is. But what happens when others' behavior is not observed? (Oskamp and Schultz, 2006).

A common problem is when a behavior is prescribed but not commonly observed. This may not encourage the behavior. This leads into the fact that decreasing pollutant discharge in storm water is a behavior that benefits a public good and sometimes does not directly reward the individual. Especially construction projects that are competitive with other construction companies might believe it is not cost efficient to follow storm water provisions if other companies are not complying. Therefore, it is important for people to believe others are doing the same behaviors in order for people to comply (Schultz, 2006).

This leads into Hardin's "The Tragedy of the Commons" concerning waste discharge in a public good or commons which is water as a sink. Hardin says the pollution problem is a consequence of population and the population problem has no technical solution. The population problem overloaded the natural recycling processes. The commons of air and water cannot be fenced like agriculture or hunting, instead it needs coercive laws or taxing that make it cheaper for the polluter to treat his pollutants than to discharge them untreated. Hardin said people need to realize the necessity of mutual coercion in order to have more freedoms. The CWA and the MS4 program is a mutual coercion to a solution to the commons of the water bodies as pollution sinks (Hardin, 1968).

Hardin also believes the only way to avoid universal ruin, including the pollution problem, is the abandonment of the commons in breeding. Hardin does say that education can counteract the natural tendency to do the wrong thing, but this knowledge needs to be constantly refreshed (Hardin, 1968). Instead of looking for a solution to the commons in breeding, I will concentrate on a large – scale modification of human behaviors (Dwyer, 1968).

Ostrum also talks about institutions for governing and managing common – pool resources. Ostrum believes people use interactions to gain a reputation for being trustworthy, and others will be willing to cooperate with them to overcome the commons problems. Ostrum says groups of people who can identify one another are more likely to care about trust and reputation to develop norms that limit use of a commons than groups of strangers. Ostrum argues that today norms have evolved from 1968 when Hardin wrote the "Tragedy of the Commons". With the use of modern technology, like the internet, geographic information systems, and the media, large groups of people are now able to monitor one another's behavior and coordinate activities to solve the commons problem.

How can storm water programs change normative beliefs?

Schultz displays two ideas: block leaders and distributing data on others behaviors. Oskamp gives the example that the leaders during the dustbowl" period serve as models for other farmers and therefore other farmers take on the new farming practices. (Oskamp) Block leaders or neighborhood leaders that promote the decreasing pollutant behavior can be effective. These leaders take responsibility for the storm water program in their neighborhood, perform the behaviors themselves, and encourage neighbors to perform behaviors that decrease pollutant discharge. Studies have shown that block leaders have a direct affect on normative beliefs. Block leaders effectively increase behaviors for a continued amount of time (Schultz, 2006).

An alternative to the EPA's strategy of using procedural information is to distribute normative information to residents. Distributing data about others behaviors could be done on the EPA website, community newsletters, newspapers, and public service announcements. This is most effective when the majority of people in an area are actually decreasing pollutant discharge or if the data is higher than the normative belief among the people in that area. Types of data could include the percentages of people who perform the behaviors each week, the percentage of car oil that is properly disposed of by the residents, or the numbers of homes that conserve water while irrigating their landscapes less.

It is important to make sure the information is specific to the individual. The type of data should provide a means for the individual to compare his behavior to the social norm. For example, the data should be from ones neighborhood instead of citywide data. Also, the data should be about a specific behavior like properly disposing car oil. This strategy of making data more personal is effective at changing behavior. Therefore, the CWA would be more effective if the education/information strategy used by the EPA included normative social influence and in order to have a sustained change of behavior the norm has to be observed (Schultz, 2006).

Convenience and incentives can also affect a motivator of behavior changes (Schultz, 2006, Ostrum, 1999). Some solutions are: treated carwashes be strategically dispersed around neighborhoods, common car oil drop offs at auto shops, car oil redemptions, tax breaks for efficient irrigation systems, cheap and available substitutes for pesticides and herbicides, and multiple trash cans along pet walking trails or parks.

Hardin also says instead of forbidding an action make it too expensive to do. For example, the cost of every industry's shares of waste they discharge into storm water is less than the cost of investing in new technology, or the cost of a fine (Hardin, 1968). It is important to include follow up measures over meaningful time periods. For long term success, a consequence must be in place for a behavior to continue (Dwyer, 1980). As long as the fine for violating storm water regulations is in place the positive behavior is likely to continue.

It is important to include follow up measures over meaningful time periods. For long term success, a consequence must be in place for a behavior to continue (Dwyer, 1980). As long as the fine for violating storm water regulations is in place the positive behavior is likely to continue.

Finally, in order for a conservation strategy to be effective one must evaluate the strategies by reporting its shortcomings. While documenting the changes in pollutants in the storm water discharge, the positive changes as well as the failures need to be reported. These failures need to be reported in order to serve as learning devices so a program can be revised, improved, and updated. Redford gives the example of a leader in an indigenous village not dispersing the funds like a western society would. The lesson learned was that indigenous organizations need to get their finances in order, watch their employees more closely, and train indigenous accountants. But because of this failure in the program, the donor threatened not to renew the funding. The renewal of funding is contingent upon success. On the other hand, if the failures are not reported then other programs will make the same mistakes and this wastes money, effort, and time. Time is something biodiversity doesn't have. If we wait to long to learn from our mistakes then biodiversity could reach an irreversible state of impairment. Successes and failures need to be stated. The learning experience makes the strategy more effective. Therefore, experimentation and "writing the wrongs" need to be apart of the CWA storm water program implementation. On the same note, all state and local governments need to share what works and doesn't work in their implementation of the storm water program. We are lucky the CWA is a federal regulation and we do not depend on donors, but there is the chance that State programs might be seen as inadequate and have their responsibility of issuing pollution permits taken away. As long as it is accepted that the EPA and the responsible States report and share what works and doesn't work, they can learn from their mistakes and improve the storm water program accordingly and ultimately the storm water program would be more effective and be a long-term success (Redford, 2000).

Knowing that storm water pollutants are the nation's biggest contributors to water pollution which is impairing biodiversity, certain conditions need to be taken into account when implementing and evaluating an effective strategy using the CWA. The CWA calls for storm water programs but uses undefined language that causes uncertainty in the implementing process causing legal disagreement and regulatory uncertainty. If the United States considered environmental protection a human right, we wouldn't be dealing with the uncertainties of the language and the discrepancies in the NPDES and storm water program. The U.S. fails to address the scientific and technological limitations when designing environmental standards and regulations. The EPA has created an extensive information and education profile on its website as strategy to help implement the storm water programs more effectively. Knowledge is a strong predictor of behavior. With the addition of motivators and normative beliefs, together these conditions can make a strategy effective. Finally the programs need to report and share the successes as well as the failures in order to learn from their mistakes and improve the program. Under these conditions the storm water program under the CWA can be more effective for a longer period of time.

Science

Objective: Is storm water an important source for organic contaminants and could the fate of these organics impair marine life in San Diego Bay?

The science portion of this project is the laboratory component which is the controlled setting representing the contamination of seawater with the PAH organics, assessing 1) sub-lethal toxicity following exposure to PAHs and 2) difference in adsorption of PAHs to various grain size of sediment found across San Diego Bay. The experiment uses a realistic range of concentrations for experimental exposure in order to address possible scenarios for description of dose-response processes in San Diego Bay. The PAH concentrations used in our experiment resemble the actual mean PAH concentrations in Chollas Creek and San Diego Bay during this last wet and dry season (2006-2007) taken from monitoring data by the City of San Diego (City of San Diego, 2006-2007).

Table 1. Annual flow weighted mean of PAH concentrations in the Creeks and San Diego Bay for this last wet season (2006-2007).		**Total PAH (ng/L)**
	Switzer	**558**
	N. Chollas	**1273**
	S. Chollas	**388**
	Paleta	**810**
	San Diego Bay	**100**

Sub-lethal toxicity was determined using the luminous brittlestar Amphipholis squamata, which is native to San Diego bay. Bioluminescence is the production and emission of light by a living organism. This species of brittlestar produces bioluminescence in its arms while the disc, or the middle of the brittlestar, does not light up (Fig. 5; Deheyn, 2000). Light production is only triggered mechanically or chemically, not spontaneously, and when triggered is under nervous control! Bioluminescence profile therefore can be used as a proxy for functionality of the nervous system, especially when the light production is stimulated using neuro-mediator. Bioluminescence can be experimentally stimulated with chemicals such as Acetyl choline (Ach) which stimulates the nervous system and measures neuro-stimulated potential of bioluminescence, and KCl, which causes tissue depolarization and measures total chemical potential of bioluminescence. Bioluminescence profile can be described using various intensity and kinetics parameters, including the total light production with time (RLU) and total area under the curve (Figure 6). The time it takes for the brittlestar to produce the amount of light up to half of the area under the curve refers to the Kinetics, or signal transduction efficiency. Brittlestars are a good indicator of toxicity because the technique is sub-lethal as opposed to the EPA's lethal bioassays (Deheyn, 2000).

Figure 5. Brittlestar bioluminescence after stimulation using KCl. The produced light is green, and transmitted along the arms following nervous stimulation. The central disk does not produce light.

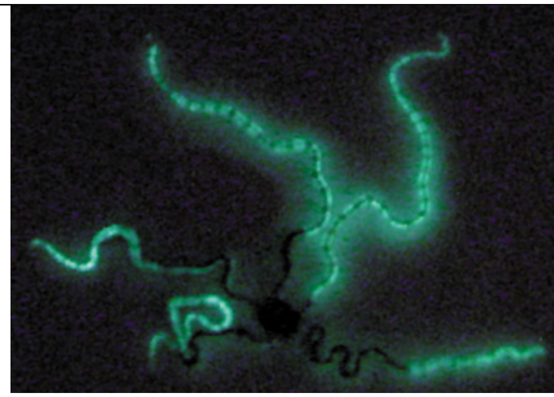
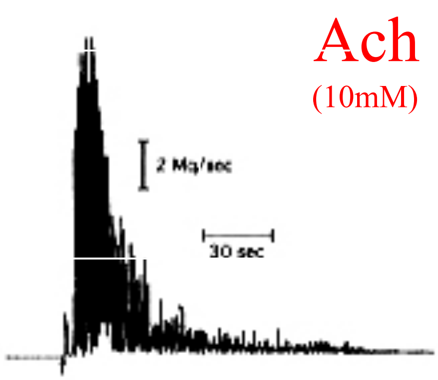


Figure 6. First two graphs display typical acetyl choline versus potassium chloride bioluminescence profiles with time. Acetyl choline profile typically has numerous light flashes while potassium chloride has a single flash. The last graph shows Intensity of light with time expressed in total relative light units (RLU). The kinetics are the time to reach half the area under the curve.



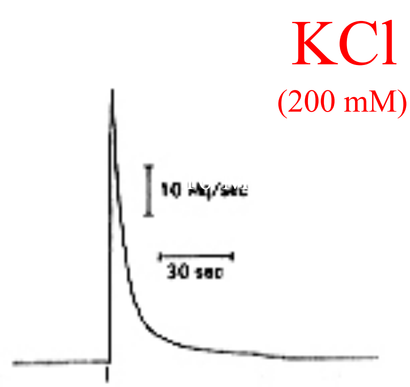
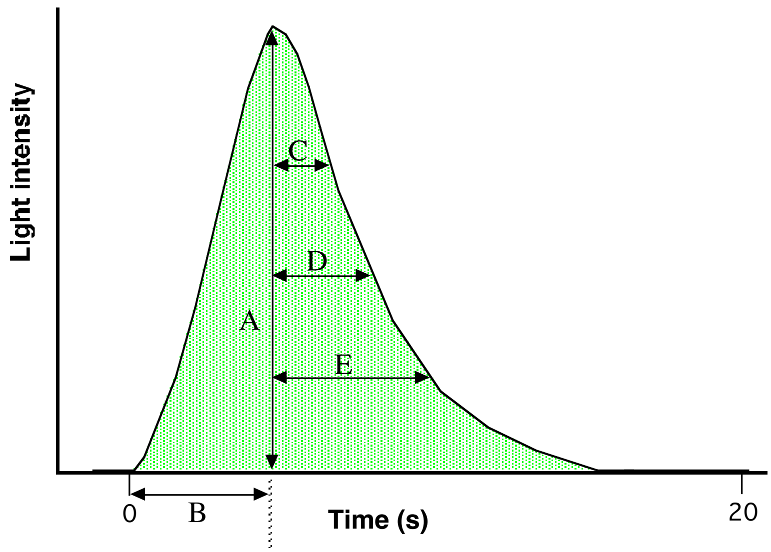


Figure 6 continued.



Deheyn et al. 1997
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Methods

I began the laboratory experiment by preparing 4 aquaria with 2 liters of "clean" seawater from the La Jolla marine preserve in front of SIO. Then I added nine individual brittlestars, *Amphipholis squamat*a, in each aquaria. I exposed the brittlestars to low (4ng/L), medium (100ng/L), and high (400ng/L) PAH concentrated environments and also acetone (400ng/L) as a control for the solution which contained the PAH mixture, and clean seawater for two weeks (water was changed after 7 days). These PAH concentrations resemble the real PAH concentrations measured in the creeks and SD Bay this last wet season. This Fisher Scientific PAH Mixture (For EPA 525.1) contains each component at 100μg/mL in Acetone: Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[ghi]perylene, Benzo[a]pyrene, Chrysene, Dibenz[a,h]anthracene, Fluorene, Indeno[1,2,3-cd]pyrene, Phenanthrene, and

Pyrene. Changes in the brittlestars light production parameters will be indicative of PAH toxicity. Bioluminescence is measured using a Berthold luminometer and any change in light parameters represents change in neuro-physiological health status, which is routinely used as a proxy of environmental quality in Deheyn's laboratory.

Figure 7. Experimental setup with 4 aquaria in which brittlestars were exposed to low, medium and high PAH concentrations, with Acetone exposure as the control.

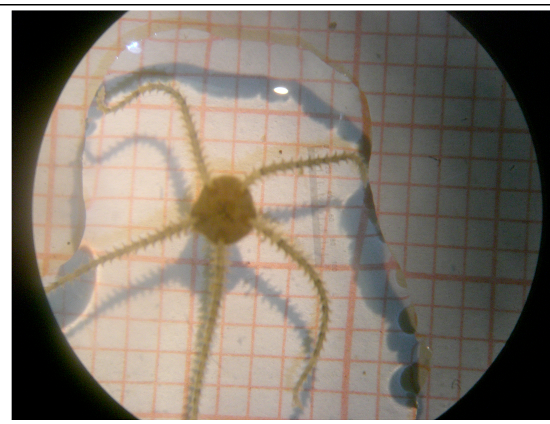


Figure 8 (left) and 9 (above). Anesthetizing, measuring, and removing arms of brittlestars for analyses under the microscope.

On day 0, 3, 7, and 14, I collected the brittlestars from their experimential condition and tested them for bioluminescence in order to monitor the brittle stars' neuro-physiological health status. To measure bioluminescence, I anesthetized the brittle stars in a pH balanced 3.5% magnesium chloride artificial seawater solution, measured the disc and arm lengths, and then removed two arms each. Each arm was placed in a test tube then into the luminometer. One test tube was injected with 50 uL of 2mM acetylcholine at 10 seconds and subsequently measured for two minutes. Then the second arm was used to test chemical capacity of the arm for bioluminescence, and was stimulated following injection of 50 uL of potassium chloride at 10 seconds, and recorded the arms' bioluminescence for two minutes. A filter (ND = 2) was then used here to avoid saturation of the luminometer due to high intensity of the light.

Measuring how much and how long it takes for PAHs to affect the individual helps assess the toxicity thresholds (Deheyn, 2006). In order to determine whether toxicity is linked to level of accumulated PAHs in tissues, PAHs were also measured from arms and disk of brittlestars. However, *Amphipholis squamata* is too small to allow analytical measure of PAHs, so I used the bigger species, *Ophiothrix spiculata* to address bioaccumulation. I placed thirty *Ophiothrix spiculata* from the La Jolla cove area into each of the three aquaria containing 2 liters of "clean" water with the low (4ng/L), medium (100ng/L), and high PAH (400 ng/L) concentrations. Then on day 0, 3, and 14, I cut and froze the arms and discs of ten individual brittle stars to test for PAH concentration in their arms versus their discs. The samples are currently in the process of being analyzed.

Figure 10. Individuals of *Ophiothrix spiculata* ready to be dissected.

Figure 11. Dissected samples of brittlestar disk and arms in tubes ready for concentration analysis (in progress).

San Diego Bay has different sizes of sediment (fine vs. coarse) and brittlestars live in these different types (Newman, 1958). Knowing when and how much PAH accumulates in the sediment helps to assess the bioavailability of the PAH or how long the PAH stays in water column in a form available to marine life (Anderson, 1996, Chadwick, 2004, Fairey, 1998, Gieskes, 2007). I used clean sandy and fine sediment collected from offshore La Jolla marine preserve to represent the various Bay sediments. Sediment was collected by grabs, clean with freshwater, and then dried for weeks in the oven (65˚C). Two hundred grams of dried fine muddy sediment was placed in one aquaria with 2 liters of SIO seawater with the highest concentration of PAH (400 ng/L) and the same for coarse sandy sediment. Continuous air bubbles flowed through tubes into the aquaria for a realistic water mixing environment. This simulates a contamination event for benthic invertebrates and determines the flux of organic contaminants from water, into sediment. I sampled sediment at day 0, 1, 3, and 14. The sediment and accumulation analyses are currently being performed.

Results

Figure 12 is the original data of light production. You can see the injection of Acetylcholine at 10 seconds and measurements until 130 seconds. The white line is the control or "clean water" and the red represents the brittlestars exposed to high PAH concentrations after 2 weeks. Without toxicity the light is produced with small flashes as seen with the white line. Obviously there's a difference between these two lines. Total light production (in Relative Light Units or RLU) and kinetics (in seconds) were measured from these raw data and mean and standard error measured from all replicates.

Graph 1 is the summary of the mean spontaneous bioluminescence for all the replicates for each day and concentration with standard error. It shows the measure of light from 0-10 seconds before injecting the chemicals. The control has low level of spontaneous light production as expected, while every other condition is higher. Light production is higher already after day 3. In certain cases, light production decreases after 2 weeks. The effect is similar for all experimental conditions, meaning that the low concentration had similar effect as the high concentration. Acetone also had an effect, which reinforce the fact that acetone is neurotoxic (Noraberg and Arlien-Soborg 2000).

Graph 2 shows the kinetics of bioluminescence stimulated with acetylcholine. The control is always lower, meaning it takes less time for the brittlestar to emit half its light; it is faster. Similar to the first graph, every other condition emits light more slowly. Also, there is a clear change after only 3 days, and the change is similar for every experimental condition.

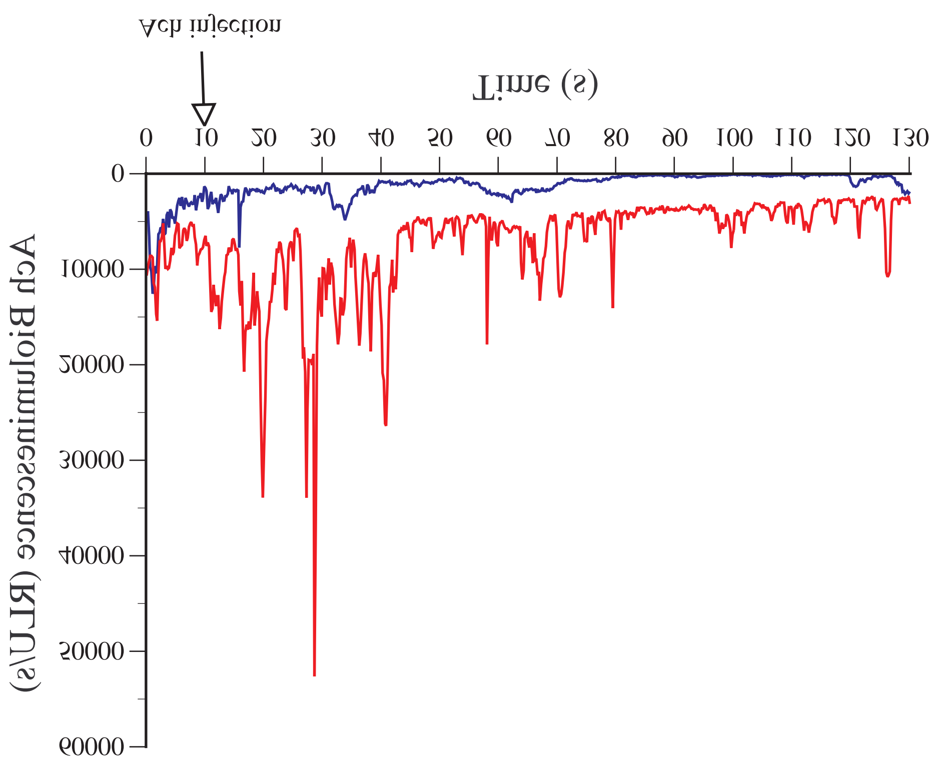
Graph 3 shows the total light after Ach stimulation of bioluminescence and indicates that more light was emitted in the treatments than the control. Again the acetylcholine injection helps show that the brittlestar cannot control light production, it just releases it all in large amount as opposed to be small low intense flashes. Therefore this graph shows the brittlestars' loss of neuro-control, thus interpreted as neurotoxicity.

The potassium chloride injection checks if the brittlestars all have the same light production capacity. Potassium chloride causes tissue depolarization and thus assesses total light production capacity. Graph 4 shows that light production did not vary in the control, while the experimental treatments show lower KCl bioluminescence. Because the brittlestars were also producing spontaneous bioluminescence upon treatment exposure, a better measure of whether light capacity changed with treatment was to express KCl bioluminescence relative to the spontaneous light, as some of the KCl variation could just be due to the fact that light has already be exhausted by spontaneous production.

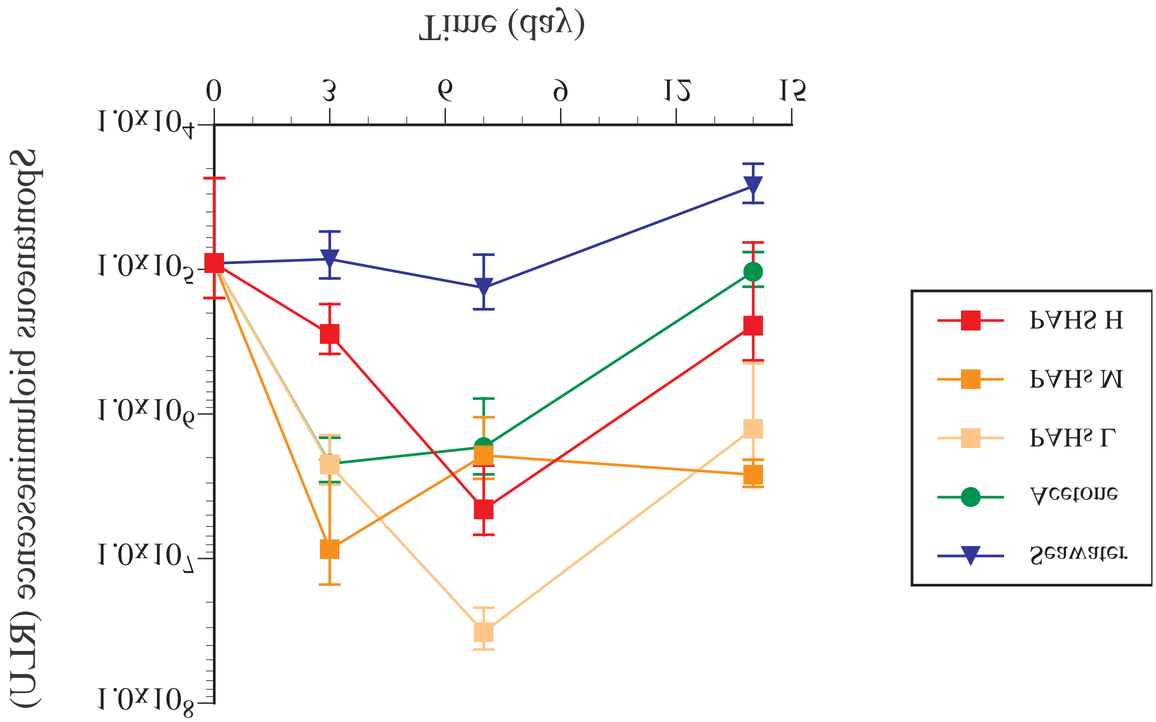
Graph 5 shows the light production induced by potassium chloride relative to the spontaneous bioluminescence. There is no significant difference between seawater and the other treatments which means any change in acetylcholine bioluminescence is not due to a difference in bioluminescence capacity. All the brittlestars have the same capacity to produce light; therefore, the difference in the acetylcholine test shows light production due to deleterious function of the nervous system, thus toxicity! All PAH concentrations similarly affected brittlestar bioluminescence using this sub-lethal test, which clearly indicates that EPA guidelines to assign toxic thresholds based on death as endpoint should be revised to more sensitive assays and mower thresholds.

The purpose of the science experiment was to determine if storm water is an important source for PAHs and whether the fate of these organics could impair marine biodiversity in San Diego bay. The experiment also helps to identifying TMDL thresholds that are ecologically relevant. Acetylcholine bioluminescence is affected and not the potassium chloride bioluminescence. Therefore sub-lethal neurotoxicity in brittlestars caused by PAH toxicity is observed. This observation is already observed within 3 days of exposure. This data can help to create a TMDL for PAHs because the low concentration of 4 ug/L already shows toxicity and within only 3 days (even though it does not trigger death). Some recommendations include staying up to date with TMDL values, measuring would need to be taken within 3 days for accurate assessment, and using a sub-lethal bioassay for measuring relevant toxicity.

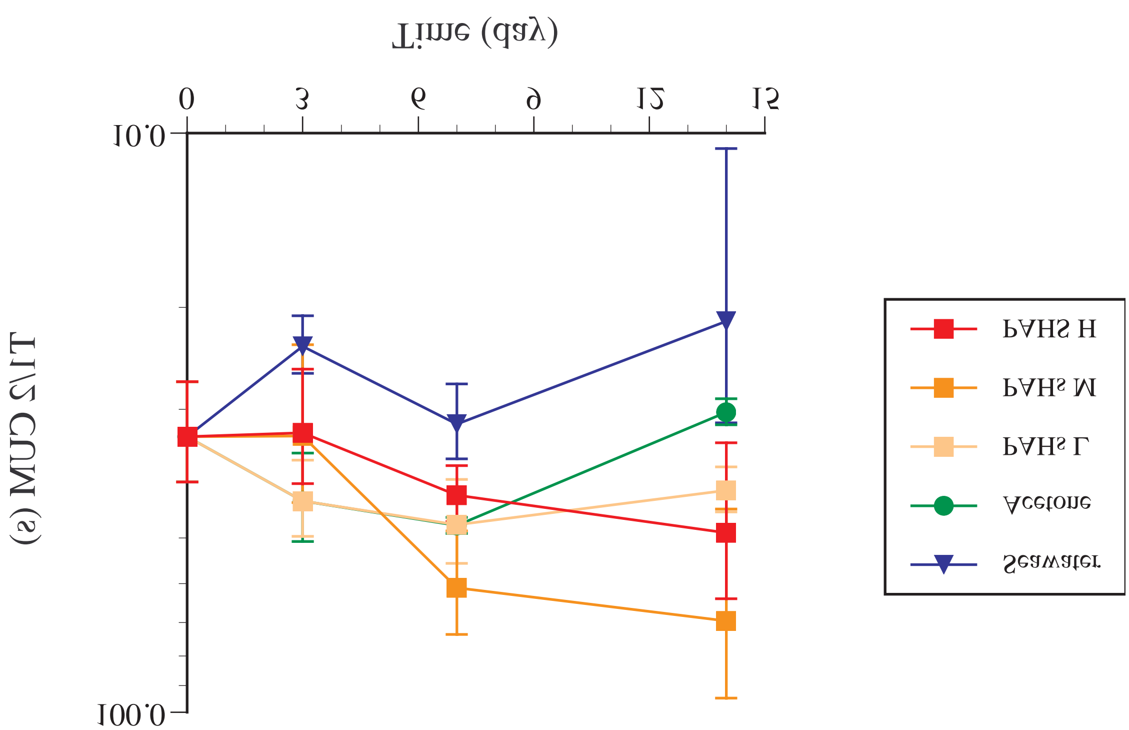
Figure 12. Original light production data.



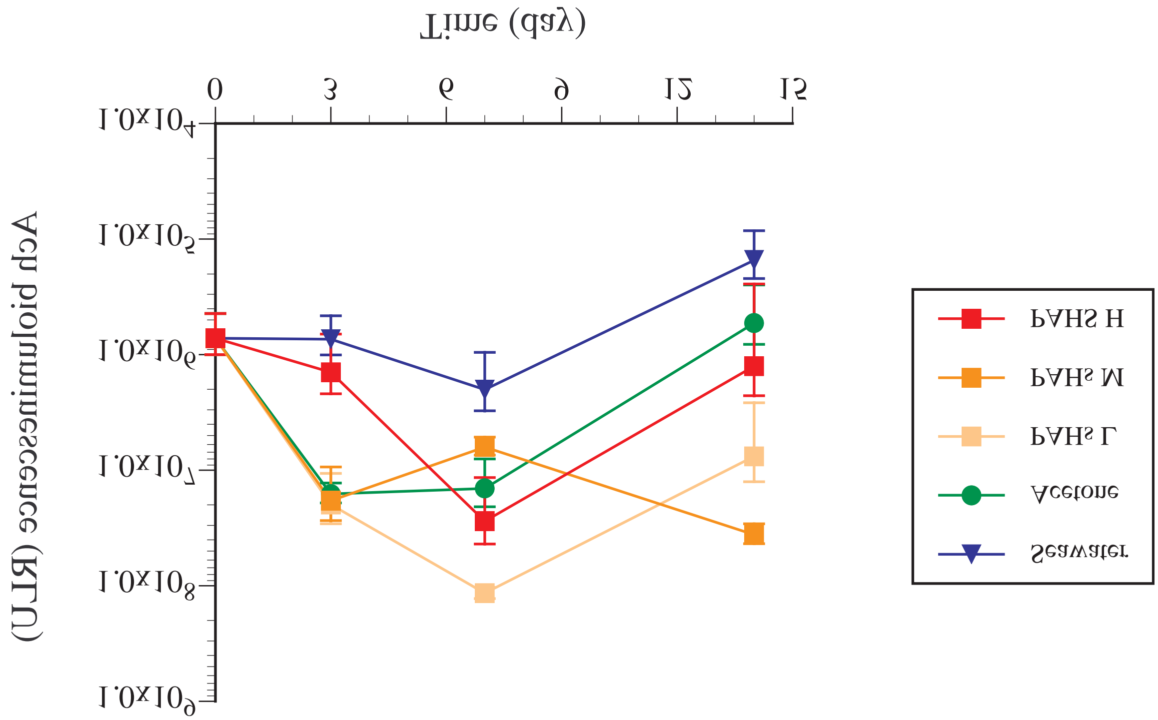
Graph 1. Spontaneous Bioluminescence



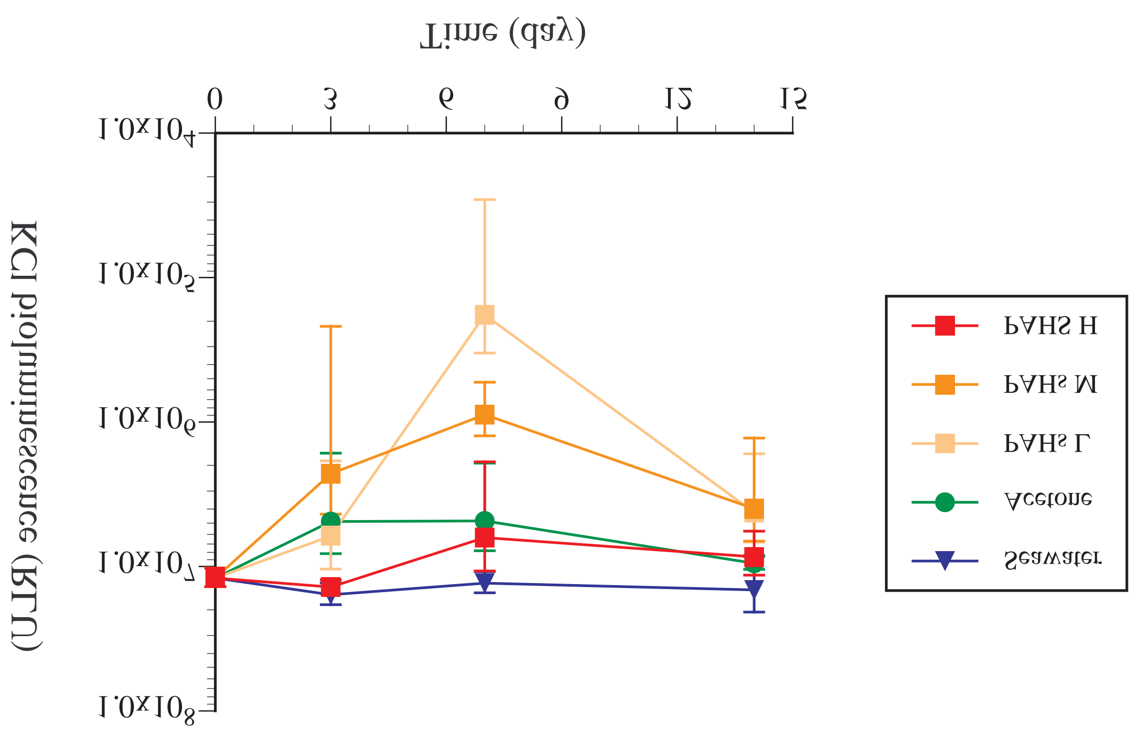
Graph 2. Acetylcholine Kinetics



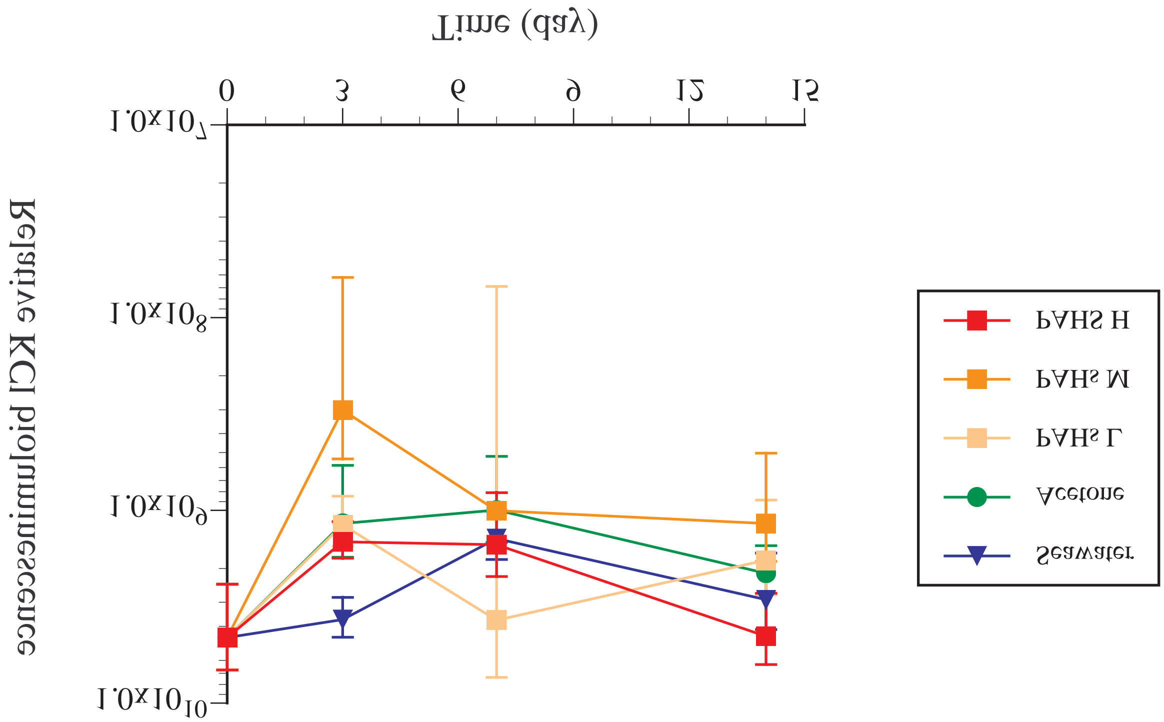
Graph 3. Acetylcholine Bioluminescence



Graph 4. Potassium Chloride Bioluminescence



Graph 5. Relative Potassium Chloride Bioluminescence



Recommendations

Ultimately, storm water is an important source for PAHs which could impair marine biodiversity in San Diego bay. The sub-lethal neurotoxicity in brittlestars caused by even the lowest concentration (4ng/L) of PAH toxicity is observed. This observation is already observed within 3 days of exposure. In order to protect San Diego bay's impaired benthic community, TMDL thresholds need to be ecologically relevant. It is important that the EPA uses more sensitive bioassays when conducting toxicity assessments, and using a sub-lethal bioassay for measuring relevant toxicity. This data can help to create a TMDL for PAHs because the low concentration of 4 ug/L already shows toxicity and within only 3 days (even though it does not trigger death). San Diego bay would also benefit from increased monitoring efforts during rain events making sure the measuring is taken within 3 days for accurate assessment.

Some other recommendations include preservation of native plants and wetlands, which can help to reduce organic contaminant loads such as PAHs from storm water before they enter the bay. Plants help with the uptake of nutrients and the transformation of contaminants. Plants modify soil physical and chemical properties by providing organic carbon substrates to adsorb contaminants. Plants also support microbial respiration, provide substrate for bacterial biofilms and migration of pollutants (Birch 2004).

Microbes, dehalogenating bacteria, and bioaccumulators found in wetlands also determine the fate of pollutants (Levin 2001). Microbes also purify water by detoxification of pollutants. Detoxification is the process where microbes take up bioavailable forms of contaminants such as metals or hydrocarbons including PAHs and transform or accumulate them (Monserrate et al. 1997). Wetlands are also good at trapping and transforming synthetic organic chemicals because these chemicals are highly particle reactive (Levin 2001). At least four bacterial species degrade organophosphates, like some insecticides, by a process called cometabolism. Lastly, bioaccumulators (for example bivalves) can retain the organics in their tissues. When predators eat the bioaccumulators the contaminants can exit or enter the wetland (Levin 2001).

Some other recommendations are to protect headwaters and wetlands which can protect our bays and ocean. Our bays and oceans would benefit from creating a Non Point Source program which is separate and unique from the Point Source Program. San Diego has done a great job increasing its water monitoring efforts and in doing so citizens' polluting behavior will change. If we begin to value clean water, maybe policy makers and citizens will be willing to fund a combined sanitary and storm sewer system.

The EPA needs to stay up to date with TMDLs and this data can help to create a TMDL for PAHs in San Diego because the low concentration of 4 ug/L already shows toxicity and within only 3 days (even though it does not trigger death). Measurements would need to be taken within 3 days for accurate assessment.

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